Defects in Heavily Phosphorus-Implanted Si
Observed after Drive-in Process
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Ion implantation is one of the useful methods to deposit impurities into the
surface of semiconductors because of the advantage that any quantity of impurity
can be deposited uniformly. However, when phosphorus is heavily doped by ion
implantation and thermal drive-in process is followed, growth of many induced
defects are usually observed. In the case of planar structure, not only high densi-
ty dislocation networks are observed within the implanted area but dislocations
which propagate laterally outside the implanted area are also observed. The latter
dislocations are called "emitter edge dislocations" in the bipolar transistor
structure, and give deleterious effects on the transistor characteristics.

We have studied about the processing factors which affected the growth of these
defects in phosphorus-implanted samples, and compared with thermally phosphorus-
deposited samples. Possible factors we initially considered were total phosphorus
concentrations, drive-in conditions(temperature and atomosphere), presence of
implantation-generated primary defects, and initial phosphorus concentration
profiles.

Si wafers were (111) oriented, p type 10Ω-cm resistivity. Phosphorus implantation
energy was varied from 25keV to 180keV, and ion doses were from 10¹⁵/cm² to 3x10¹⁶
/cm². Thermal deposition was performed using POCl₃ source at the temperature between
1050°C and 1150°C. Temperature of drive-in process was also varied from 1000°C to
1200°C. Defects were observed by the transmission electron microscopy, X-ray
diffraction topography and chemical etching.

Some important results obtained from our experiments are as follows.
1. "Emitter edge dislocations" appeared only after oxidizing drive-in process
and they were remarkable in wet O₂ atomosphere. These dislocations and dislocation
networks were observed in the samples of relatively low phosphorus concentration
(above 5x10¹⁵/cm²), whereas, in thermally deposited samples, no defect was observed
after oxidizing drive-in process even at the phosphorus concentration of 4x10¹⁶/cm².
Drive-in in nonoxidizing atomosphere(dry N₂ or dry Ar) generated no "emitter edge
dislocations" even in the 3x10¹⁶/cm² phosphorus implanted sample. Dislocation net-
works were observed near the surface, but they were confined within the implanted
region and they seemed not to traverse the junction. Dislocation networks and
"emitter edge dislocations" observed by transmission electron microscopy is shown
in Fig.1.
2. Presence of primary defects lowered the threshold phosphorus concentration above which induced defects were observed to grow. Si ions were implanted into the thermally phosphorus-deposited samples to generate primary defects at the energy of 50keV and doses from $10^{14}$/cm$^2$ to $1.5\times10^{16}$/cm$^2$. After drive-in in wet $O_2$ atmosphere at 1100°C, dislocation networks and "emitter edge dislocations" were observed around the patterns implanted above $10^{15}$/cm$^2$ Si ions. Results of chemical etching of this case are shown in Fig. 2.

3. Anomalous compressive strain was observed by the X-ray diffraction topography around phosphorus doped region in oxidized samples which showed "emitter edge dislocations". Whereas, in samples drive-in in nonoxidizing atmosphere, usual tensile strain was observed. This anomalous strain is supposed to have the important effect upon the generation of "emitter edge dislocations". Schwuttke reported the anomalous compressive strain observed in the thermally phosphorus diffused samples and he speculated that the anomalous strain might relate to the excess phosphorus near the surface. In our case, the excess phosphorus is not the main origin of the compressive strain. In the sample of Fig.2, tensile strain was observed before etching in the left side pattern and compressive strain was observed in the right side pattern. Presence of primary defects and oxidation process seem to have important relation to the generation of the compressive strain.

References